

INCLINED LINK AS SHEAR REINFORCEMENT IN
REINFORCED CONCRETE BEAM

AMINUDDIN BIN SUHAIMI

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Specially dedicated to my parents and beloved wife.

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ABSTRACT

The sudden failure of reinforced concrete beams due to shear made it necessary to explore more effective ways to design these beams. The effects on the shear capacity of reinforced concrete beam were investigated with three different arrangements of shear reinforcement; vertical link, inclined link and inclined link with additional bar. The mode of failure was secured to allow for shear failure. All beams were casted with the same grade of concrete, provided with identical amount of main reinforcement, simply supported and tested under symmetrical two-point loads at shear span. The study shows that the contribution of inclined links to the shear capacity is significant and directly proportional to the amount and spacing of the shear reinforcement. The increase in the shear capacity ranged from 18% to 33% compared with the control beam. Ultimate shear resistance was also compared with the analytical calculation according to Eurocode 2 (EC 2) and American Concrete Institute (ACI). Performance of the beams in resisting shear is in the form of deflection, cracking, strains in the reinforcement, strains in concrete, and ultimate load. It may therefore be suggested that these types of shear reinforcement can be used to ease the congestion of links near the supports, thus, savings in the amount of steel bars.

ABSTRAK

Kegagalan secara tiba-tiba pada rasuk konkrit bertetulang disebabkan oleh ricih telah menimbulkan keperluan untuk menerokai kaedah yang lebih berkesan bagi merekabentuk rasuk-rasuk ini. Kesan keatas keupayaan ricih pada rasuk konkrit bertetulang dikaji dengan tiga jenis tetulang ricih; perangkai pugak, perangkai condong dan perangkai condong dengan bar tambahan. Mod kegagalan telah dikawal bagi membolehkan kegagalan ricih berlaku. Semua rasuk dibina dengan gred konkrit yang sama, dengan bilangan tetulang utama yang sama, disokong mudah, dan diuji di bawah dua titik beban yang simetri di rentangan ricih. Kajian ini menunjukkan bahawa sumbangan perangkai condong kepada keupayaan ricih adalah signifikan serta berkadar terus dengan jumlah dan jarak tetulang ricih. Peningkatan keupayaan ricih bagi rasuk yang diuji adalah antara 18% hingga 33% berbanding dengan rasuk kawalan. Rintangan ricih muktamad turut dibandingkan dengan pengiraan analitikal berdasarkan Eurocode 2 (EC 2) dan American Concrete Institute Code (ACI). Prestasi rasuk dalam menghalang ricih adalah dalam bentuk nilai pesongan, keretakan, keterikan dalam tetulang, keterikan dalam konkrit, dan beban muktamad. Oleh yang demikian, tetulang ricih jenis ini boleh dicadangkan bagi mengurangkan kesesakan perangkai ricih berhampiran penyokong rasuk, lantas menjimatkan bilangan bar keluli.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xv
	LIST OF APPENDICES	xvii
1	INTRODUCTION	
	1.1 General	1
	1.2 Importance of study	3
	1.3 Objectives	3
	1.4 Scope of study	4
2	LITERATURE REVIEW	
	2.1 Shear	5
	2.2 The typical behavior of Shear in concrete beam	7
	2.3 Evaluation of experimental shear strength increase due to stirrups	10
	2.4 Types of Shear reinforcement	13

2.4.1	Shear reinforcement of a beam with vertical links	14
2.4.2	Shear reinforcement of a beam with inclined links	18
2.4.2.1	ACI code provision	19
2.4.2.2	EC 2 code provision	20
2.5	Stress-strain relations of steel	22
2.6	Stress-strain relations of concrete	23
2.7	Summary	25

3 EXPERIMENTAL INVESTIGATION

3.1	Introduction	27
3.2	Details of test specimens	28
3.2.1	Details of beam AS-C	28
3.2.2	Details of beam AS-T1	29
3.2.3	Details of beam AS-T2	31
3.3	Material properties	32
3.3.1	Formwork	32
3.3.2	Concrete	33
3.3.3	Steel reinforcement	36
3.4	Concrete casting	36
3.5	Slump test	37
3.6	Compression tests: Cube test	37
3.7	Instrumentation	39
3.7.1	Steel strain gauge	39
3.7.2	Linear Variable Differential Transformers (LVDT)	40
3.7.3	DEMEC strain gauge	41
3.8	Test procedures	43

4 TEST RESULTS

4.1	Introduction	45
4.2	Concrete properties	46
4.3	Beam AS-C	46

	4.3.1 Test results	48
4.4	Beam AS-T1	52
	4.4.1 Test results	54
4.5	Beam AS-T2	58
	4.5.1 Test results	60
4.6	Summary to the beam test results	64
5	ANALYSIS AND DISCUSSIONS	
5.1	Introduction	65
5.2	Cube compressive strength of the normal concrete	66
5.3	Analysis and Discussion of test results	66
	5.3.1 Load-Deflection behavior	66
	5.3.2 Cracking behavior	78
	5.3.3 Steel strain	70
5.4	Comparison between experimental and analytical results	71
6	CONCLUSIONS AND RECOMMENDATIONS	
6.1	Conclusion	73
6.2	Recommendation	74
	REFERENCE	76-78
	Appendices A-F	79 -115

TABLE OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Value of v_c design concrete shear stress (Table 3.8 – BS 8110-1: 1997)	17
3.1	Materials proportions of concrete mix	34
4.1	Concrete compression strength	46
4.2	Summary of test results	64
5.1	The difference in percentages on the ultimate loading capacity as compared control beam, AS-C	67
5.2	The difference in percentages of deflection at failure as compared to control beam, AS-C	67
5.3	The difference between calculation value and testing results	72

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	C-C – Shear plane	6
2.2	Principal stresses in a beam	6
2.3	Modes of Shear failures	9
2.4	Flexural failure	10
2.5	Forces in the Shear span at inclined crack	12
2.5(a)	Beam only longitudinally reinforced	12
2.5(b)	Beam with stirrups	12
2.5(c)	Concrete cantilever and triangle of forces at truss joint	12
2.6	Types of Shear reinforcement	14
2.6(a)	Vertical stirrups	14
2.6(b)	Inclined stirrups	14
2.6(c)	Bent-up-bars (two groups)	14
2.7	Vertical links intercept the cracks in the concrete	15
2.8	Vertical links and the analogous truss	15
2.9	Inclined links	18
2.10	Truss model and notation for shear reinforced members	21
2.11	Stress-strain for steel reinforcement	23
2.12	Stress-strain for concrete	24
3.1	Steel reinforcement detailing for beam AS-C	29
3.2	Nominal links and vertical stirrups arrangement of beam AS-C	29

3.3	Steel reinforcement detailing for beam AS-T1	30
3.4	Nominal links and inclined stirrups arrangement of beam AS-T1	30
3.5	Steel reinforcement detailing for beam AS-T2	31
3.6	Nominal links and inclined stirrups together with the additional bar arrangement of beam AS-T2	31
3.7	The completed formwork of beam specimens	32
3.8	G-Clamps is provided on the formwork during the casting process	33
3.9	150mm x 150mm x 150mm concrete cubes mould	35
3.10	Curing process of which the beams were covered with wet hessian	35
3.11	Compression strength test machine	38
3.12	Steel strain gauges location on the longitudinal bars	39
3.13	Linear variable differential transformers (LVDT)	40
3.14	Location of LVDTs, directly below the loading points	41
3.15	Digital DEMEC strain gauge	42
3.16	Location of DEMEC discs	42
3.17	Testing frame and setup	44
3.18	Experimental setup for beam specimens	44
4.1(a)	Beam AS-C failed in shear	47
4.1(b)	Shear cracks on the both side of shear region	47
4.2	Load-Deflection relationship for beam AS-C	49
4.3(a)	Load-Steel strain relationship for beam AS-C (Left-end side)	49
4.3(b)	Load-Steel strain relationship for beam AS-C (Right-end side)	50
4.4(a)	Load-Concrete strain relationship for beam AS-C (Left-end side)	50

4.4(b)	Load-Concrete strain relationship for beam AS-C (Right-end side)	51
4.5(a)	Load-Crack width relationship for beam AS-C (Left-end side)	51
4.5(b)	Load-Crack width relationship for beam AS-C (Right-end side)	52
4.6(a)	Beam AS-T1 failed in crushing	53
4.6(b)	Shear cracks on the both side of shear region and failed in moment region	53
4.7	Load-Deflection relationship for beam AS-T1	55
4.8(a)	Load-Steel strain relationship for beam AS-T1 (Left-end side)	55
4.8(b)	Load-Steel strain relationship for beam AS-T1 (Right-end side)	56
4.9(a)	Load-Concrete strain relationship for beam AS-T1 (Left-end side)	56
4.9(b)	Load-Concrete strain relationship for beam AS-T1 (Right-end side)	57
4.10(a)	Load-Crack width relationship for beam AS-T1 (Left-end side)	57
4.10(b)	Load-Crack width relationship for beam AS-T1 (Right-end side)	58
4.11(a)	Beam AS-T2 failed in shear	59
4.11(b)	Shear cracks on the both side of shear region	59
4.12	Load-Deflection relationship for beam AS-T2	60
4.13(a)	Load-Steel strain relationship for beam AS-T2 (Left-end side)	61
4.13(b)	Load-Steel strain relationship for beam AS-T2 (Right-end side)	61
4.14(a)	Load-Concrete strain relationship for beam AS-T2 (Left-end side)	62
4.14(b)	Load-Concrete strain relationship for beam AS-T2 (Right-end side)	62

4.15(a)	Load-Crack width relationship for beam AS-T2 (Left-end side)	63
4.15(b)	Load-Crack width relationship for beam AS-T2 (Right-end side)	63
5.1	Shear resistance-beam relation	72

LIST OF SYMBOLS

A	-	Area of a cross-section
A_s	-	Area of tension reinforcement
A_{sb}	-	Area of steel in bent-up bars
$A_{s,prov}$	-	Area of tension reinforcement provided
$A_{s,req}$	-	Area of tension reinforcement required
A_{sv}	-	Total cross-sectional area of links at the neutral axis
a	-	Shear span
b	-	Width of beam
b_v	-	Breadth of member for shear resistance
c	-	Cover to reinforcement
d	-	Effective depth
f_{cu}	-	Characteristic concrete cube strength at 28 days
f_s	-	Service stress in reinforcement
f_{tt}	-	Design tensile stress in concrete at transfer
f_y	-	Characteristic strength of reinforcement
f_{yb}	-	Characteristic strength of inclined bars
f_{yv}	-	Characteristic strength of link reinforcement
L	-	Effective span of a beam
M	-	Bending moment
M_{max}	-	Maximum bending moment
s_b	-	Spacing of bent-up bars
s_v	-	Spacing of links
V	-	Shear force at ultimate design load
V_b	-	Design ultimate shear resistance of bent-up bars
V_c	-	Design ultimate shear resistance of a concrete section
ν	-	Shear stress

v_b	-	Design shear stress resistance of bent-up bars
v_c	-	Design shear stress resistance of a singly reinforced concrete beam
α	-	Angle between a bent-up bar and axis of a beam
β	-	Bond coefficient
θ	-	Angle
ϕ	-	Bar diameter

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Analysis of singly reinforcement rectangular section	79
B	Concrete mix design for Grade 35	83
C	Detail for testing results beam AS-C	85
D	Detail for testing results beam AS-T1	93
E	Detail for testing results beam AS-T2	104
F	Calculation for shear resistance	111

CHAPTER 1

INTRODUCTION

1.1 General

One of the main objectives of the design of reinforced concrete beams is to ensure the safety of the occupants. Sudden failure due to low strength shear is not a desirable mode of failure. Reinforced concrete beams are designed primarily for flexural strength and shear strength. Beams are structural members used to carry loads primarily by internal moment and shear. In the design of a reinforced concrete member, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary resistance for moments.

Limits are placed on the amounts of flexural reinforcement to ensure that the beam has sufficient ductility behaviour at failure for safety reasons. This is then followed by shear reinforcement design. Since shear failure is sudden with little or no early warning, the design for shear must ensure that the shear strength for every member in the structure exceeds the flexural strength. The shear failure mechanism varies depending on the cross-sectional dimension, geometry, types of loading, and the properties of the member.

During the design stage, whenever the value of actual shear stress exceeds the permissible shear stress of the concrete, the shear reinforcement must be provided. The purpose of shear reinforcement is to prevent shear failure by increasing the ductility of the beam and considerably reduces the likelihood of a sudden failure.

Inclined shear crack normally started at the middle height of the beam near the support at approximately 45° and extended towards the compression zone. Any forms of effective anchored reinforcement that intersects these diagonal cracks will be able to resist the shear forces to a certain extent. In practice, shear reinforcement is provided whether in the form of vertical links, inclined links, inclined bent-up bars and also a combination of vertical and horizontal bars.

Vertical links are most commonly used as shear reinforcement in building construction, for their simplicity in fabrication and installation. Normally, spacing between links is reduced to resist high shear stress. Congestion near the support of the beams due to the presence of the closely spaced links is sometimes unavoidable. Apart from that, the fixing of shear reinforcement which is closely spaced is time consuming and increases the cost of materials.

It is generally accepted that the inclined reinforcement improves the ductility and increases the energy dissipation capacity of a reinforced concrete member. Experimental and analytical research [1],[2] have confirmed that if the steel grid in a shear reinforced concrete element is set parallel to the direction of the applied principal stresses, the cyclic response of the shear element is maximized to a limit that the shear-dominant element behaves similar to flexural-dominant element.

In this study, three reinforced concrete beams with the same grade of concrete and size were tested using the vertical links system and the inclined links system. Two types of inclined links systems were used to study the effect of inclined links configuration on the shear load carrying capacity of the beams. The first beam,

AS-C, is used as a control beam with vertical links as shear reinforcement. Meanwhile, the other two beams were reinforced with inclined links. Beam AS-T1 is reinforced with inclined links tied to the longitudinal top and bottom bars, while beam AS-T2 is designed with additional bar, which was added to the rectangular shaped inclined links and tied to the longitudinal top and bottom bars.

All the tested beams were designed so that it will fail solely in shear. Therefore, adequate amount of tension reinforcement were provided to give sufficient bending moment strength and the test results were compared.

1.2 Importance of Study

Providing experimental data of the effect of inclined links on the shear capacity of a reinforced concrete beam. The test data will be of great benefit especially for guidance in structural assessment.

1.3 Objectives

The main objectives of this study are as follow:

- a) To investigate the shear capacity of beams with inclined links.

- b) To compare the results between inclined links and vertical links calculated according to Eurocode 2 (EC 2) [3] and American Concrete Institute Code (ACI) [4].
- c) To study the effectiveness of inclined links as shear reinforcement.

1.4 Scope of Study

This study is based fully on the experimental investigation to be carried out with the scope given below.

- a) The study was based on experimental investigation on three reinforced concrete beams.
- b) All specimens were of the same size, 200 mm width \times 250 mm height \times 2000 mm length and reinforced with identical amount of longitudinal steel, 3T16 as tension reinforcement and 2T12 as compression reinforcement.
- c) The beams were tested to failure under two point loads near the support to give a shear span-to-effective depth ratio (a/d) of less than 2.0.
- d) The concrete compressive strength of the beam specimens is designed to achieve 35 N/mm² at 28 days.
- e) The variables in the specimens were the shear reinforcement systems, which are vertical links, inclined links and inclined links with an additional bar. The inclination of the inclined links was 45° from the longitudinal axis.

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